AFRPL-TR-71-30

AD 725706

INTRODUCTORY GUIDE TO EXPLOSIVES, HANDLING AND DEVICES

R.M. ZEEK, MAJ, USAF

TECHNICAL REPORT AFRPL-TR-71-30

APRIL 1971

AIR FORCE ROCKET PROPULSION LABORATORY
DIRECTORATE OF LABORATORIES
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
EDWARDS, CALIFORNIA

71-101

71-3680 59

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Air Force Rocket Propulsion Laboratory Edwards, California 93523	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

Introductory Guide to Explosives, Handling and Devices

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Guide (August 1970)

5. AUTHOR(S) (First name, middle initial, last name)

R.M. Zeek, Maj, USAF

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
April 1971	56 & vii	0

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. N/A	AFRPL-TR-71-30
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Air Force Rocket Propulsion Laboratory Air Force Systems Command, USAF Edwards, California 93523

13. ABSTRACT

Material presented in this publication is offered as an introduction to the handling of explosives and to explosive devices. The information is directed primarily to those unfamiliar with explosives and is also intended as a review for those engaged in frequent care and movement of explosives. The material is not to be considered as complete or authoritative. Where detailed information is necessary, the proper authority has been referenced. In all cases, safety officers should be consulted.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Explosives Handling						
Explosive Devices						
Explosives Storage						
Explosives Classification						
Quantity-Distance						
Fuses						
Shaped Charges						
Electro-initiating Devices						
Igniters						
Ignition Trains						

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FOREWORD

This guide was prepared by Major R. M. Zeek, USAF, at the Air Force Rocket Propulsion Laboratory, Edwards, California, during August 1970. The work was conducted within the Solid Rocket Division at AFRPL.

This technical report has been reviewed and is approved.

B. R. WARREN
Project Engineer
Solid Rocket Division

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Material presented in this publication is offered as an introduction to the handling of explosives and to explosive devices. The information is directed primarily to those unfamiliar with explosives and is also intended as a review for those engaged in frequent care and movement of explosives. The material is not to be considered as complete or authoritative. Where detailed information is necessary, the proper authority has been referenced. In all cases, safety officers should be consulted.

TABLE OF CONTENTS

LIST OF FIGURES

WARNING

The information contained within this publication is not to be considered authoritative. Where detailed information is necessary, the proper authority has been referenced. In all cases, consult a safety officer.

SECTION I

TRANSPORTATION

DEPARTMENT OF TRANSPORTATION

The Department of Transportation (DOT) is the governing body and final authority controlling the movement of explosives and other dangerous articles by common carrier.

Air Force manuals 75-1, 75-2, 75-4, 127-100(X) and U.S. Coast Guard regulations will apply to Government as well as commercial shipments.

In addition to the foregoing, each state and nearly all municipalities have laws or ordinances regulating the transportation of explosives and other dangerous articles within their jurisdiction.

WARNING

EXPLOSIVE ITEMS MAY NOT BE MAILED UNDER ANY CIRCUMSTANCES.

Industrial growth of the country in past years increased the demand for transporting some commodities which could be dangerous if handled improperly. This presented the country with a serious safety problem. Congress enacted legislation to cope with this problem. As a result, the Department of Transportation formulates regulations for the safe transportation of explosives and other dangerous articles that are binding upon: (1) all carriers engaged in interstate or foreign commerce which transport explosives or other dangerous articles by land, and (2) upon all shippers making shipments of explosives and other dangerous articles via any carrier engaged in interstate or foreign commerce by land or water.

The congressional legislation also provides severe penalties for a person who knowingly delivers to a carrier or for a carrier and knowingly transports such dangerous articles in violation of the regulations of the Department of Transportation (DOT). The DOT has issued extensive regulations pursuant to the congressional action.

TRANSPORTATION CLASSES

For transportation, explosives are divided into three classes:

Class A explosives: detonating or otherwise, of maximum hazard
Class B explosives: flammable hazard
Class C explosives: minimum hazard

A representative list of products falling into these categories follows:

Class A Explosives:

Initiating explosives, including PETN
High explosives, including RDX
Dynamite
Blasting caps and electric blasting caps (more than 1000)
Shaped charges, including linear-shaped charges
Explosive bombs

Class B Explosives:

Double-base propellants with less than 20 percent nitroglycerin
Cannon and rifle powders
Solid propellant, rubber base

Class C Explosives:

Blasting caps and electric blasting caps (1000 or less)
Cordeau detonant fuse (primacord)
Percussion fuses, combination fuses, time fuses, etc.
Igniters
Fuse lighters and igniters
Instantaneous fuses
Primers
Safety fuses

SHIPMENT

Class C explosives may be shipped by any mode of transportation: air, water, rail, truck or railway express. (The U.S. Post Offices does authorize some Class Class C explosives in mail service, i.e., safety fuse, pullwire lighters, hot-wire lighters.)

Normally, Class A explosives may be shipped via rail only. Only a limited number of motor carriers have authority to haul Class A explosives. Air service is not available for Class A explosives except on a "plane charter" basis, which is expensive.

Shipments of explosives may be made upon request of the Department of the Army, Navy and Air Force via any carriers, whether or not they hold authority. In addition, there are government air freight services, such as LOGAIR, Westover AFB, Massachusetts, which may be used when commercial carriers cannot perform and when the shipment is for a DOD contract. The contractor must obtain authorization for the LOGAIR-type service, not the supplier, although the supplier has to do a good deal of coordinating.

Shipments of explosives offered by or consigned to the Departments of the Army, Navy, and Air Force must be packed, within limitations of weight, in accordance with the DOT regulations, or in containers of equal or greater strength and efficiency as required by the DOT.

The Department of Transportation does not have jurisdiction over the airlines, but the Federal Aviation Authority will honor the Class C designation and authorize airlines to handle this material in cargo planes when packed in accordance with DOT regulations. Not all airlines are willing to accept this material.

New explosives cannot be shipped until samples are approved by the Bureau of Explosives and a shipping classification is assigned. But it is permissible to ship samples for laboratory examination by rail freight or rail express without prior approval by the Bureau of Explosives provided they fulfill these requirements:

1. Must be packed in well-secured metal cans or glass bottles, or in strong waterproof paper or cardboard packages; each sample must consist of not more than 1/2 pound of explosive, and the interior package must be placed in sawdust or similar cushioning material, at least 2 inches thick, in a wooden box, specification 14 or 15A.

2. Whenever these samples of explosives are contained in a metal envelope or receptacle, the receptacle must be properly cushioned with sawdust or similar cushioning material in a strong wooden box, and this interior box must be packed in a wooden box, specification 14 or 15A, with at least 2 inches of cushioning material separating the boxes.

3. The net weight of the explosive contents must be plainly marked by the shipper on the outside of each box.

4. Each outside box have the proper label for laboratory samples.

It is also permissible to ship (by rail freight or rail express without Bureau of Explosives authorization) new military explosives approved by the Chief of Ordnance Department of the Army; Chief, Bureau of Naval Weapons, Department of the Navy; or Commander, Air Force Systems Command; and Commander, Air Force Logistics Command, Department of the Air Force.

SUMMARY OF TRANSPORTATION REQUIREMENTS

Transportation of explosives and hazardous materials is regulated by the Department of Transportation, currently under "Agent T. C. George's Tariff No. 23," issued 3 August 1969 and effective 3 September 1969.

Air Force regulations concerning transportation of explosives are contained in Section 7 of AFM 127-100, "Explosives Safety Manual," 20 April 1964.

State of California regulations for shipment of hazardous materials may be found in Highway Patrol Manual No. 84.2, "Hazardous Materials Transportation," dated December 1968. It is published by the Motor Carrier Safety Section, CHP Headquarters, Sacramento, California.

Requirements of the Air Force Rocket Propulsion Laboratory may be found in TI 4-7-3, "Technical Instruction, Requirements for Shipping Propellants, Rocket Motors, Igniters, etc.," dated July 1967.

SECTION II

STORAGE, CLASSES, QUANTITY-DISTANCE AND COMPATIBILITY

STORAGE

Storage magazines are generally constructed in two basic designs aboveground and underground (igloo).

The aboveground type has concrete floors and piers, a framework of steel, double pitch roof supported on steel trusses over a ceiling of corrugated asbestos with fireproof rock wool insulation. The walls may be concrete or hollow tile, sand filled.

The most common type of storage magazine is the underground igloo. It is not actually underground but earth covered on top sides and one end. Construction consists of reinforced concrete foundation, rear and front walls, an arched roof, and a built-in membrane waterproofing the arch and rear wall. The concrete used in construction of the igloo-type magazine is formulated so as to pulverize under the force of an explosion.

Both types of magazines are provided with adequate ventilation and all metal parts are grounded.

CLASSES FOR STORAGE

Classes of explosive have recently been realigned by military nomenclature into numerical groups. In general, they are:

Class 1 - Items which will present, primarily, a fire hazard producing no blast and virtually no fragmentation or toxic hazard, i.e., small arms ammunition, fuse lighters, distress signals, etc.

Class 2 2a 2b	-	Items which will burn vigorously with little or no possibility of extinguishing fires. Explosions normally confined to pressure ruptures of containers which do not produce propagating shock waves, i.e., pyrotechnics, solid propellant in bulk, and cannon and rifle propellant.
Class 3	-	Items which will explode progressively, generating small and light fragments.
Class 3 4 5 6	-	Combined to cover items whose principal hazards may be fragmentation, toxicity or blast, either individually or in combination. Items in these classes may explode or detonate progressively when involved in fire or when otherwise initiated.
Class 6	-	Items assigned to this class usually explode progressively by stacks and are principally a blast hazard.
Class 7	-	Items assigned here must be stored in a single magazine. The principal hazard is mass detonation.
Class 8(T)	-	Items may be expected to detonate en masse, however, they contain only small amounts of explosive and produce light missiles of limited range, i.e., blasting caps, detonators, etc.
Class 8	-	CBR agents and munitions items not normally assembled with explosive components.
Class 12	-	Items which are relatively insensitive and can be initiated only by very strong means, i.e., ammonium nitrate, primacord, etc.

QUANTITY-DISTANCE CONSIDERATIONS

To reduce to a minimum the hazards and risks due to fire and explosion, regulations are prescribed that govern:

1. The distance to be maintained between magazines and public highways, public buildings, public railways and inhabited buildings.

2. The distances to be maintained between magazines.

3. The maximum quantity permitted in any one magazine.

Examples of quantity-distance are presented in Figures 1 and 2.

STORAGE COMPATIBILITY

Two or more types of explosives are said to be compatible when their characteristics are such that a quantity of the items stored together are no more hazardous that a comparable quantity of any of the items stored alone.

Explosives are grouped for compatibility upon the basis of:

1. Quantity of explosives per unit
2. Sensitivity to initiation
3. Effects of involvement in fire
4. Effects of explosion
5. Rate of deterioration
6. Type of packing

The compatibility groups are identified by the use of the letters A through Q.

(2) **Intermagazine separation for Special Igloos and Aboveground Magazines:**

TABLE 5-8. CLASS 7 (9-10)—INTERMAGAZINE SEPARATION FOR SPECIAL IGLOO AND ABOVEGROUND MAGAZINE

Net Pounds of Explosives		*Distance In Feet Between Magazines*			
		Special Igloo		*Aboveground* [4,5]	
Over	*Not Over*	*Bar* [2]	*Unbar* [3]	*Bar*	*Unbar*
0	100	20	40	30	50
100	200	26	52	35	64
200	300	30	60	40	74
300	400	33	66	44	81
400	500	35	70	50	85
500	750	41	82	54	100
750	1,000	45	90	60	110
1,000	2,000	55	110	75	140
2,000	3,000	65	130	85	160
3,000	4,000	70	140	95	175
4,000	5,000	75	150	105	190
5,000	7,500	85	170	115	215
7,500	10,000	95	190	130	235
10,000	20,000	120	240	165	300
20,000	30,000	140	280	185	340
30,000	40,000	155	310	205	375
40,000	50,000	165	330	220	405
50,000	60,000	175	350	235	430
60,000	70,000	185	370	245	455
70,000	80,000	195	390	260	475
80,000	90,000	200	400	270	495
90,000	100,000	210	420	280	510
100,000	125,000	225	450	300	550
125,000	150,000	240	480	320	585
150,000	175,000	250	500	335	615
175,000	200,000	265	530	350	645
200,000	225,000	275	550	365	670
225,000	250,000 [1]	285	570	380	695
250,000 [1]	500,000	[6]	[7]	[8]	[9]

[1] Maximum quantity permitted in any one special igloo or aboveground magazine without specified approval for the deviation (see para 0105). See notes 6 through 9.

[2] Barricaded separation will apply to special igloo where a barricaded door end or earth covered side or back of one igloo faces the exposed earth covered sides, backs, or doors of the other igloos involved.

[3] Unbarricaded separation will apply where special igloos are so located that the unbarricaded door zone (see para 0524.4 for an explanation of this zone) of one igloo without a door barricade encompasses an earth covered side, back or barricaded door of another igloo. Magazines will not be so located that the unbarricaded door end of one igloo faces the unbarricaded door end of another igloo. Should such conditions exist, unbarricaded Aboveground Magazine Distance will apply.

[4] Use unbarricaded distances unless barricades meet the requirement of para 0524. Aboveground barricaded distances may be used between aboveground magazines and the barricaded portions of igloos.

[5] Aboveground intermagazine separation will be applied to open storage, railroad cars, vehicles and aircraft containing these explosives (see paragraph 0511 and 0519).

[6] Distances for any proposed location of these quantities will be based upon 4.5 times the cube root of the weight of explosives ($d = 4.5\sqrt[3]{w}$).

[7] Distances for proposed locations will be based upon $d = 9\sqrt[3]{w}$.

[8] Distances for proposed locations will be based upon $d = 6\sqrt[3]{w}$.

[9] Distances for proposed locations will be based upon $d = 11\sqrt[3]{w}$

Figure 1. Example: Table 5-8, Page 5-26.1 of AFM 127-100D, 7 September 1966

(3) Intraline separation:

TABLE 5-9. CLASS 7 (9-10)—INTRALINE SEPARATION

Net Pounds of Explosives		Distance In Feet[2]	
Over	Not Over	Bar	Unbar
	50	30	60
50	100	40	80
100	200	50	100
200	300	60	120
300	400	65	130
400	500	70	140
500	600	75	150
600	700	80	160
700	800	85	170
800	900	90	180
900	1,000	95	190
1,000	1,500	105	210
1,500	2,000	115	230
2,000	3,000	130	260
3,000	4,000	140	280
4,000	5,000	150	300
5,000	6,000	160	320
6,000	7,000	170	340
7,000	8,000	180	360
8,000	9,000	190	380
9,000	10,000	200	400
10,000	15,000	225	450
15,000	20,000	245	490
20,000	25,000	265	530
25,000	30,000	280	560
30,000	35,000	295	590
35,000	40,000	310	620
40,000	45,000	320	640
45,000	50,000	330	660
50,000	55,000	340	680
55,000	60,000	350	700
60,000	65,000	360	720
65,000	70,000	370	740
70,000	75,000	385	770
75,000	80,000	390	780
80,000	85,000	395	790
85,000	90,000	400	800
90,000	95,000	410	820
95,000	100,000	415	830
100,000	125,000	450	900
125,000	150,000	475	950
150,000	175,000	500	1,000
175,000	200,000	525	1,050
200,000	225,000	550	1,100
225,000	250,000[1]	575	1,150

[1] Maximum quantity permitted in any one location without specific approval for the deviation (see par. 0105).

[2] Use unbarricaded distances unless barricades meet the requirements of par. 0524.

Figure 2. Example: Table 5-9, Page 5-26.2 of AFM 127-100D, 7 September 1966

Please note in the following examples of compatibility groups that quantities of a single Group . item may not be mixed with another Group A item. Each item must be stored separately.

0425.1 Group A (Separate Storage):

Chemical munitions, Group A

Chemical munitions, Group B

Chemical munitions, Group C

Chemical munitions, Group D

Dynamite (commercial)

Fuses, chemically actuated

Grenades, rifle, AT (pentolite loaded)

Pentolite-loaded ammunition except pentolite-loaded rifle grenades (see prior item)

Photoflash powder

Pyrotechnic materials except items in storage compatibility Groups C and K

0425.2 Group B:

Adapter booster

Ammunition, caliber 30mm or less (including AP-I but excluding HE and/or HE-I rounds and 20mm or 30mm incendiary rounds).

Boosters

Boosters, auxiliary

Bursters

Cartridge-actuated devices (CAD), complete rounds

Cartridge, bomb ejection

Cartridges for cartridge-actuated devices

Charge igniter, assembly, for fuse M10 and M10A1

0425.6 Group F:

Catapult, rocket

Rocket motors (JATO)

Rocket, HE, complete rounds

Rocket warheads, HE (without motor)

Rockets, practice

Solid propellant environmental samples for associated rocket motors

CAD items associated with the foregoing

0425.9 Group I:

Charge, demolition

Demolition blocks

Detonating cord (primacord)

Dynamite (military)

Grenades, hand offensive

Shaped charges (except pentolite loaded)

0425.10 Group J:

Cartridge, engine starter

Propellant, solid, Class 2

Propellant, solid, Class 2A

Propellant, solid, Class 2B

Propellant, solid, Class 7

Solid propellant environmental samples for associated stored propellant

Complete information, discussions and tables concerning these subjects are provided in AFM 127-100 (see Bibliography).

SECTION III

FUSES (BURNING AND DETONATING)

PYROTECHNIC TIME DELAYS

Timeline* is a pyrotechnic delay encased in a metal sheath for use in missile and other defense applications. It provides a nonelectric delay initiating system. Timeline is identical to MDF (mild detonating fuse) in appearance, the only difference being core composition. (Timeline is a pyrotechnic or burning column whereas MDF is a deflagrating or detonating column.)

Sheath materials consist of lead and various lead alloys, well suited for small core loads where flexibility is required. Aluminum is used where greater structural integrity and a lighter product is required, generally in heavier core loads.

Pyrotechnic delays offer many advantages over electrical or mechanical ones:

1. In general, they contain no moving parts.

2. They offer a wide time-delay range.

3. They can be smaller and lighter than mechanical and electrical delays.

4. Large amounts of energy are available in small weight and volumes.

5. Usually, fabrication costs are less than mechanical or electrical delay devices.

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*Registered Trademark of Ensign-Bickford Co.

Pyrotechnic delays are available in a wide range of burning rates and sizes:

Inverse Burn Rate (milliseconds per inch)	Nominal OD (inches)
115	0.105
160	0.212
430	0.105
4100	0.212
6000	0.212
10000	0.212

An ideal delay composition is one which has a long-term storage characteristic, relative insensitivity, low gas output, high ash retention, and easy producibility. It should also have a small standard deviation of burn rate over a wide temperature range, at least -65 to +200°F.

It is important to conduct and transfer heat away from the reacting composition, and therefore the body which encases the delay column acts as a heat sink. It must be massive enough to transfer, at a constant rate, enough of the heat generated so that the temperature at the burning front remains approximately constant.

Variation with temperature is a function of core composition and mounts to about 5 to 10 percent shift for each 100°F. Variation in burn rate due to pressure has little effect.

MILD DETONATING FUSE

A mild detonating fuse (MDF) is an explosive core encased in a seamless case used to propagate an explosive detonation between input and output

booster charges. Core loads are generally in the range of 1 to 5 grains per foot with detonation rates in the range of 6000 to 8000 meters per second.

CONFINED DETONATING FUSE

Confined detonating fuse (CDF) is MDF in a confining structure which is designed to contain all of an explosive's detonation products so they neither damage adjacent equipment or personnel, nor contaminate the environment through which the CDF is routed. Such protection is especially important in space vehicles and escape capsules. CDF is used to convey an explosive signal from a point of initiation to an output function such as motor ignition, initiation of a separation assembly, etc.

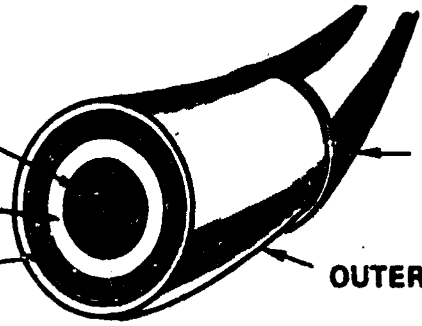
Confining structures must be strong enough to contain the detonation, but they must also be tailored to meet other system and environmental requirements. Confinement with flexibility is often achieved by encasing the MDF with multiple layers of fiberglass and one or more continuous plastic jackets. Stainless steel tubing and braided stainless steel structures are also commonly used.

SAFETY FUSE*

Safety fuse is a medium through which fire is conveyed at a continuous and uniform rate to a blasting cap or explosive charge. It consists of a train of special black powder made expressly for fuse, supported and enclosed in various wrappings of textile and waterproofing materials.

The fire is contained within these wrappings, and emerges at the end of the powder train as a jet of flame, called the "ignition" or "end spit."

*CAUTION: Do not confuse safety fuse with primacord (detonating cord).



PRIMACORD*

Primacord is a detonating (exploding) cord used primarily for initiating explosions. It can be described simply as a very strong, flexible cord with an explosive core. When primacord is initiated with a blasting cap, it detonates along its entire length at a velocity of approximately 21,000 feet (nearly 4 miles) per second.

Primacord, when detonated, has the initiating energy of a blasting cap at all points. As a trunkline it will initiate any number of additional lengths, extensions or branch lines through simple knot connections.

Primacord affords a high degree of safety. It is insensitive to extraneous electric currents and has been subjected to severe abuse, such as friction and impact, without causing a single accidental detonation so far as can be determined.

Despite these safety considerations it is designed to explode. Consequently, it should be handled, stored and used with the respect and common sense afforded an explosive.

The explosive core of standard primacord is made up of various loads of PETN (pentaerythritetetra-nitrate), i.e., x-grains per foot of core.

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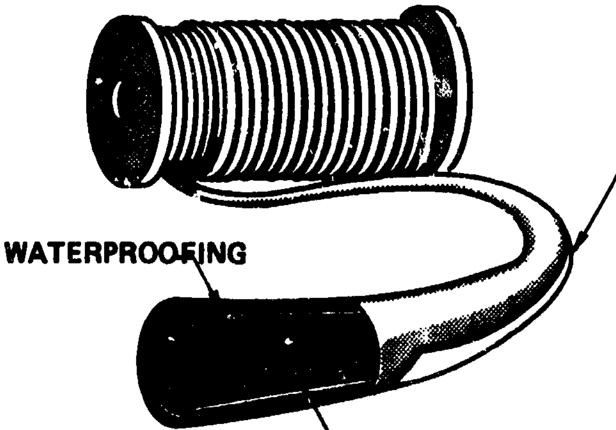
*CAUTION. Do not confuse primacord with safety fuse.

The core is covered by various combinations of materials such as textiles, waterproofing compounds, plastic, etc.



DETONATING CORD

SECTION IV

SHAPED CHARGES

SHAPED CHARGE EFFECT

The shaped-charge effect (also known as Munro effect, Neumann effect and cavity effect) was originally observed by Baader of Norway in 1799. Since that date, scientists of many countries have experimented with the phenomenon. Charles Munro, American chemist and explosives expert, gave it considerable publicity in 1888, as did Neumann, a German scientist, in 1910. As a result, it frequently bears their names. The principle of the effect can be summarized as follows:

1. If two explosive surfaces are at an acute angle to each other and are simultaneously detonated, the shock waves and expanding gases from each surface will reinforce each other at their point of intersection, so that the pressure and velocity of the gases at this point are considerably greater than that found for either of the two fronts. As a result, the gases in the vicinity of the point of intersection stream out at a high velocity along a line bisecting the angle of the junction of the original surfaces. This high-velocity gas stream is known as a jet or jet stream and it is this process which is known as the shaped charge or cavity effect.

2. Although any depression in a block of explosive will result in producing some degree of jet action, a conical recess produces by far the strongest and most efficient jet. This is due to the fact that in a cone-shaped recess, the expanding gases are moving from all directions toward the center of a plane perpendicular to the axis of the cone. By the same token, a semispherical recess is also effective in producing jet action but is not as good as a cone. The conically shaped recess is used in almost all military ammunition utilizing the shaped-charge principle.

3. After the jet is formed, the gases in the jet stream have what is called a velocity gradient. This means simply that the gases in the

front of the jet have the highest velocity, and the velocity falls continuously all the way to the rear. As a result of the velocity gradient, the jet stream stretches like a rubber band as it proceeds away from the site of the detonation.

4. The effectiveness of the jet stream is based to a considerable extent upon the length of the jet. There is a certain critical length of the jet at which optimum penetration of the target material is attained. In order to allow the jet to attain this length before it strikes the target, it is necessary to detonate the shaped charge at a distance from the target which is determined by the diameter of the cone and its included angle. This distance is known as the standoff distance and is usually equal to two to three times the base diameter of the cone. For this reason, HEAT projectiles are always constructed so that they detonate at a distance from their target rather than in direct contact with a target.

5. The effectiveness of a shaped charge may be greatly increased by lining the conical recess with a metal such as copper. If such a charge is detonated, the copper cone is collapsed toward the axis of the cone, and a jet, including copper, is formed. This jet of metal and gas has such a great penetrating power that a charge of only 1 ounce of explosive having a copper cone only 1-1/2 inches in base diameter can penetrate 5 inches of hard steel. A similar charge with an unlined conical cavity would penetrate only about 1 inch of steel.

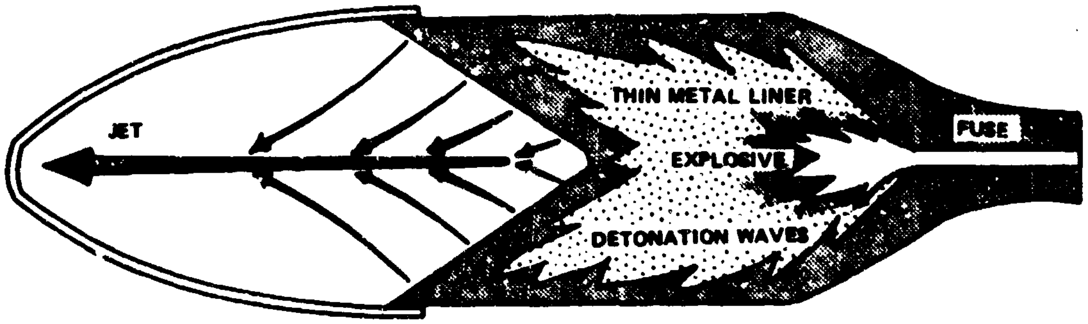
6. Only a small part of the copper cone is squeezed out to form the jet. The majority of the cone ends up as the "slug" which rather resembles a caliber .30 bullet tapered at both ends. This slug ends up with a velocity of only 400 to 500 ft/sec as compared to the velocity of around 30,000 ft/sec found at the head of the jet.

7. Penetration of a jet into armor plate results from the fact that a stream of gas or metal moving at such a high velocity exerts such an

enormous pressure (up to 500,000 atmospheres or 7,000,000 psi) against the target that the steel flows radially away from the point of impact. The hole thus formed is many times the diameter of the jet. When the jet breaks through the armor plate, it is accompanied by a spray of incandescent metal which will ignite any flammable material.

LINEAR SHAPED CHARGE

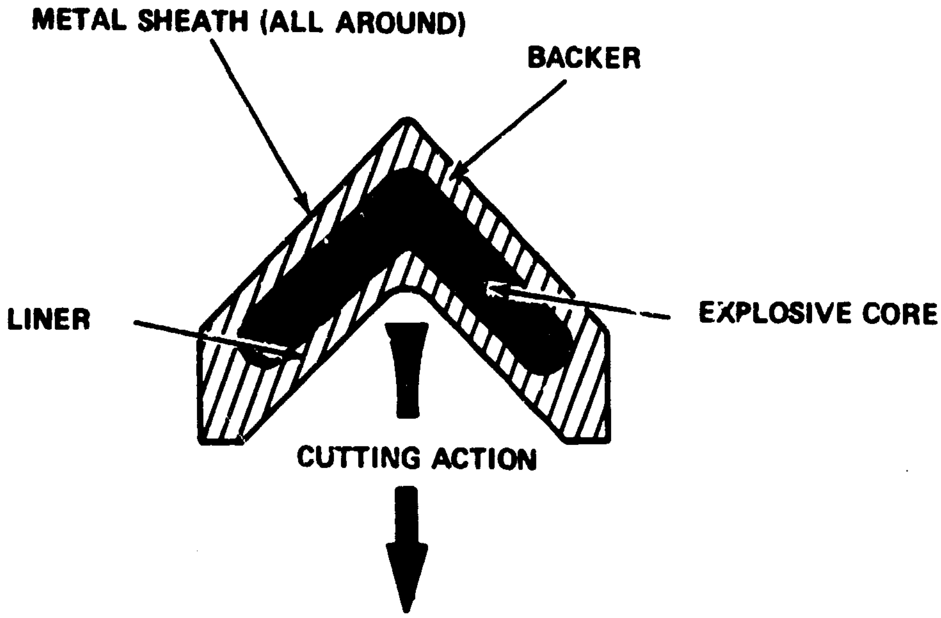
The linear shaped charge is a continuous explosive core enclosed in a seamless metal sheath. Shaped in the form of an inverted "V," the continuous liner and explosive produce a linear cutting action. This application of the Munro effect is enhanced by careful control of charge dimensions and configuration as well as liner and backer thickness and uniformity.



FLSC and ALSC

Lead flexible linear-shaped charge (FLSC) and aluminum linear-shaped charge (ALSC) are widely used for stage separation, vehicle destruct, emergency escape systems and many other applications where remote, fast and reliable cutting of materials is required. Properly designed FLSC assemblies are unaffected by severe vibration and shock and have an inherent reliability limited normally only by the initiation mechanism.

A variety of shapes have been evaluated in the development of effective FLSC, and the most efficient (Configuration IV) is presently available, sheathed either with lead (FLSC) or aluminum (ALSC) in core loads of 5 to 400 grains per foot.



Explosives Used

RDX, cyclotrimethylenetrinitramine, is colorless in its "natural" state, but is usually dyed pink for use in detonating cord.

Specification	MIL-R-398
Melting Point	204°C
Autoignition	405°C
Degradation	350°F after 1/2 hour
	325°F after 1 hour
	300°F after 4 hours

Maximum recommended prolonged storage temperature +250°F

Detonation rate 8200 meters/sec at 1.65 g/cc

HMX, cyclotetramethylenetetranitramine, a homolog of RDX, is white to colorless and often used when temperature requirements are slightly higher than recommended for RDX. HMX is very similar to RDX in output and susceptibility to initiation.

Specification	MIL-H-45444
Melting Point	273°C
Autoignition	380°C
Degradation	425°F after 1/2 hour
	400°F after 1 hour
	375°F after 4 hours

Maximum recommended prolonged storage temperature +300°F
Detonation rate 9100 meters/sec at 1.84 gm/cc

PETN, pentaerythritoltetranitrate, is somewhat more sensitive and slightly less powerful than RDX and is used primarily in Primacord R and detonators.

Specification	MIL-P-387
Melting Point	141°C
Autoignition	272°C
Degradation	250°F after 1/2 hour
	225°F after 1 hour
	200°F after 4 hours

Maximum recommended prolonged storage temperature +150°F
Detonation rate 8300 meters/sec at 1.7 gm/sc

Sheath Materials Used

Several metals are used for the linear-shaped charge, each of which has its particular advantages:

1. Lead, 6 percent antimonial per MIL-L-18331, is used most commonly and is best suited for the smaller charges when flexibility is required.

2. Aluminum, the purest and dead-soft, is used when greater structural integrity is needed, generally in heavier core loads.

3. Silver is often used in conjunction with thermally resistant explosives.

4. Copper is used for special "heavy core" applications.

Performance

The cutting ability of linear-shaped charge is a function of detonation rate and characteristics of the sheath material and is affected by the hardness and strength as well as the density of the material being cut.

Penetration and cut of a given material are essentially proportional to the square root of the core load. Actual data with improved shapes such as Configuration IV show an exponent of 0.6; i.e.,

$$\frac{T_1}{T_2} = \frac{W_1}{W_2}^{0.6}$$

where T_1 and T_2 are total cut of a given material and W_1 and W_2 are core loads.

Generally, penetration is equal to about 50 percent of total cut with fracture accounting for the balance. This relationship depends upon the strength and hardness of the material being cut which, in turn, relate to environmental conditions, most notably temperature.

Materials other than metal are also effectively cut with FLSC. These include those such as tubing and wire bundles, ablative material, composite honeycomb, fiberglass-reinforced laminates, nylon strapping and tubing.

SECTION V

EXPLOSIVES

In this section, the intent is simply to acquaint or re-acquaint the reader with those explosives most commonly employed in tests at AFRPL.

In general, an explosive is a chemical mixture or compound which, when properly initiated, undergoes a rapid chemical change. This change results in the release of heat energy and vast quantities of gas, causing a sudden rise in pressure within the explosive container.

Explosives are classified as low or high explosives as determined by their rate of burning or decomposition.

Low explosives are usually deflagrating materials which burn or decompose at a slow rate, producing a large volume of gas. They are best suited for gun propellants.

High explosives exhibit an extremely high burning rate and may be transformed into gases which expand to as much as 10,000 times the volume of the original solid. The speed of this transformation is usually in excess of 2000 ft/sec and is termed a detonation.

Most of the explosives used at AFRPL are classified as high explosives, and some pertinent data on a few representatives follows.

TNT

Trinitrotoluene was first produced in Germany and, because of its wide use in World Wars I and II as a bursting charge explosive, is considered the most important military explosive

TNT is one of the least sensitive of the military explosives and because of its suitability for melt-loads, is a most important ingredient in binary explosives and eutectic mixtures.

Physical Properties

Physical properties of TNT are:

Impact sensitivity (cm/2 kg)	95 to 100+
Explosion temperature (^{o}C)	475 (decomposes in 5 seconds)
Melting point (^{o}C)	81
Detonation rate (m/sec)	~6700
Brisance	High
Sensitivity	Detonable by No. 6 blasting cap
Color	White to buff

Principal Uses

TNT is used principally for bombs, artillery and mortar shells, grenades, and as an initiating agent.

COMPOSITION B

Because of the availability of RDX in quantity and its superiority over TNT, with respect to brisance and power, the British developed Composition B during the period between World Wars I and II, and it was standardized by the United States early in World War II.

Compositions consisting of RDX and TNT are designated as cyclotols, and Composition B consists of 55-40 cyclotol, to which has been added a wax for desensitization. Composition B therefore contains:

RDX	60.0 percent
TNT	40.0 percent
WAX	1.0 percent

Physical Properties

Impact sensitivity (cm/2 kg)	75
Explosion temperature (°C)	278 (decomposes in 5 seconds)
Melting point (°C)	78 to 80
Detonation rate (m/sec)	7840
Brisance	High, > TNT
Sensitivity	Detonable by No. 6 blasting cap
Color	Yellow-brown

Principal Uses

Composition B is used chiefly in fragmentation bombs, HE projectiles, grenades and shaped charges.

PENTOLITE (50/50)

Pentolite is manufactured by either a slurry method or by coprecipitation of PETN AND TNT. It was standardized during World War II with the 50/50, PETN/TNT mixture being the more important for bursting charges and booster-surround charges. PETN and TNT form a eutectic mixture.

The simple formulation calls for:

PETN	50 percent
TNT	50 percent

Physical Properties

Impact senstivity (cm/2 kg)	34
Explosion temperature (°C)	220 (decomposes in 5 seconds)
Melting point (°C)	76
Detonation rate (m/sec)	7465
Brisance	High. Slightly higher than TNT
Color	Yellow-white

Principal Uses

Pentolite is used principally in shaped charges, bursting charges and demolition blocks.

COMPOSITION C-4

Developed during World War II after a British plastic demolition explosive. C-4 is the last developed and standardized of a series of like explosives and is improved from the standpoint of hardening, volatility and hygroscopicity. It is a putty-like material that has found application in demolition blocks and specialized uses.

C-4 contains the following ingredients:

RDX	91.0 percent
Polyisobutylene	2.1 percent
Motor Oil	1.6 percent
Di (2-Ethylhexyl) SEBACATE	5.3 percent

Physical Properties

Impact Sensitivity (cm/2 kg)	100 +
Explosion temperature (^{o}C)	290 (decomposes in 5 seconds)
Detonation rate (m/sec)	8040
Temperature Usage (^{o}F)	-70 to +170
Sensitivity	Detonable by No. 6 blasting cap
Color	Dirty white to light brown

Principal Uses

The chief use for C-4 is as a plastic demolition explosive.

SECTION VI

ELECTRO-INITIATING DEVICES

Almost all commonly used, electrically initiated squibs, primers and detonators look alike. The metal cups, containing the pyrotechnic or explosive powder charge, are usually gilding metal (copper), cadmium-coated copper, aluminum or stainless steel. They differ only in dimension. So beware, and know what device you plan to use and make certain (by container identification) that the device you plan to use is in actuality the one being assembled. Within the last several years, some devices have had identifying marks imprinted on the surface of the cup. But many, of older manufacture, will have no marking or else the marking may have been worn off. If the identity of the device or a box of them is not known and cannot be traced, then scrap them.

Another warning must be given, and that is: know the electrical characteristics of the known device. Knowing the electrical characteristics will give an indication as to how sensitive the device might be to handling and static electricity. Some devices have no bridgewire circuit. (These will have high ohmage resistance.) These devices are known as carbon-bridge type circuits or conductive mix circuits. They are very sensitive to static charge and should only be used when low electrical energy firing current demands their use. Make certain that the lead wire legs are shunted (wound or clipped) tog‹ ›r, until a final hook-up is made. The safest way to handle any of the ‹ ›evices is by the lead wires near the device and with the device pointed away.

Normally, bridged circuits have a fine nichrome, platinum or other resistance-type wire soldered or welded at the end of the lead legs. The bridgewire is carefully selected and soldered to a predetermined length to the lead legs to give a relatively uniform resistance. A bead of heat-sensitive primary explosive material is applied to or around the bridgewire, and when proper electrical energy is applied to the lead wires, the

bridgewire becomes white hot momentarily and nearly simultaneously (less than a millisecond), the bead material bursts into flame, igniting the next charge in line (pyrotechnic or primary explosive).

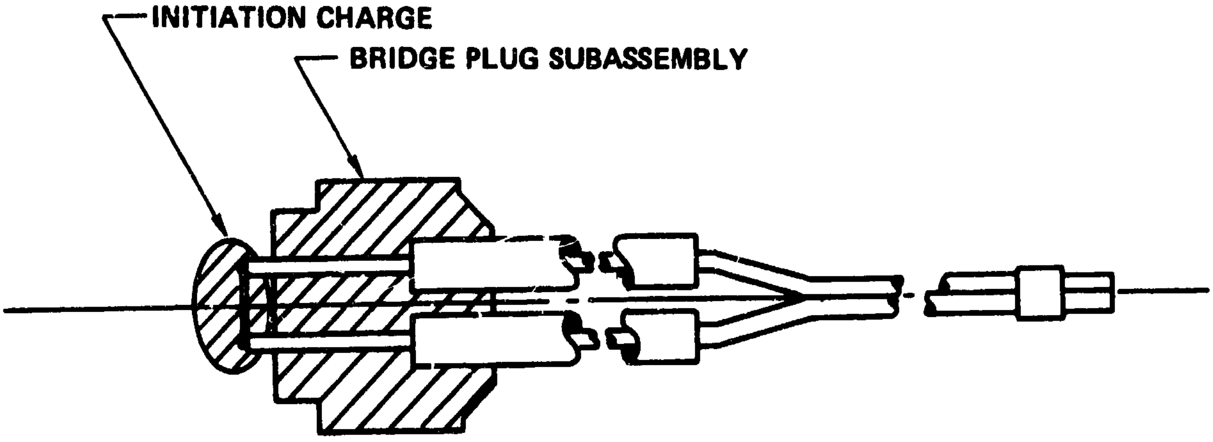
1 AMPERE/1WATT AND EXPLODING BRIDGEWIRE DEVICES

Recently, the services have sought ways to protect ordnance in areas of high-intensity radar from inadvertently supplying enough current to fire the ordnance electrical-initiating devices. Lead wires in ordnance take many different shapes and length, and in these odd configurations, could pick up various ultra-high frequencies and then warm the wire bridge portion of the initiator up to the point of initiation. To provide some measure of protection, the following are the most common methods applied: (1) design the bridgewire area with provisions for heat capacity: 1 ampere/1 watt to 5 amperes/5 watts for 5 minutes, (2) use in-line filters in or near the bridgewire to absorb or bleed off specific ranges of radar attenuation bands, (3) use exploding bridgewire devices using normal diameter bridgewire and incorporate a closely machined air gap in one leg of the lead wire portion of the device. A large surge (voltage) is required to jump the air gap, and when it does, it disintegrates the bridgewire with the sudden surge of electrical energy. These devices are quite expensive and require special gear for the completed firing circuit.

SQUIBS

Electric squibs are electric matches producing a flame and gas output. Some flames are flashes of short duration, some have additional metals in the output charge to make the flame coruscative (sparklers) and some, by construction of case and material used, are of deflagrative character. However, squibs are never designed to provide enough energy to produce a detonation.

Basic construction and examples are provided in Figures 3,4 and 5.



BRIDGE PLUG ASSEMBLY

Figure 3. Squib, Example No. 1

DIMPLE, BELLOWS AND PISTON ACTUATORS

These devices perform work by:

Dimple Motor:	Ballooning-out the output end of the case. See Figure 6.
Bellows Motor:	Extending themselves from one-half to double the original length. See Figure 7.
Piston Actuator:	Extend a rod at the output end by about one-half to two-thirds the length of the device. See Figure 8.

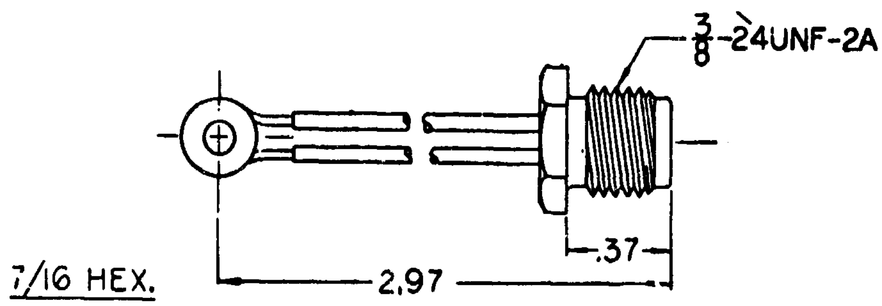
All of these devices are used to apply energy to a switch mechanically, move another device in line from safe to armed position, etc. They are "one-time" devices, and each completely contains the gases involved in making the movement.

EXPLOSIVE ORDNANCE

NO. M-32 MOD V ELECTRIC SQUIB, DWG. NO. 2024

Data contained herein is intended to be information only and should not be used as the basis for any specification.

DESCRIPTION: The M-32 MOD V Electric Squib/Pressure Cartridge was developed in 1954 to meet requirements for a screw-in squib having flexible lead wires. The unit can be used as an electric squib for initiation of igniter materials or can be used as a pressure cartridge for actuation of mechanical devices with pressurized gas. The M-32 MOD V should not be used for direct ignition of solid propellants.



SPECIFICATIONS

SHUNT: USMC No. SE-64 eyelet crimped to lead wires.

LEAD WIRE: .035 diameter steel. (AISI B-1113 or equivalent). Lead wire insulation; 20 guage spaghetti tubing per MIL I-631.

CERAMIC: Withstands 5,000 psi applied in 10 milliseconds. Dielectric strength is a minimum of 2 megohms at 500 volts D.C..

CASE: 7/16 inch hexagonal steel. (AISI B-1113 or equivalent).

MAIN CHARGE: 120 mg McCormick Selph No. 147 powder.

CHECK OUT CURRENT: 10 milliamps or less.

IGNITION BEAD: McCormick Selph No. 26 metal oxidant type.

BRIDGEWIRE: .004 diameter nichrome. Bridgewire resistance 0.30 ± .05 ohms.

CLOSURE: .003 aluminum crimped and sealed with red epoxy.

FINISH: Electro-tin plate per MIL T-10727.

UNIT WEIGHT: 4.850 grams.

RECOMMENDED INSTALLATION TORQUE: 30 in. lbs..

RECOMMENDED FIRING CURRENT: 5 amps.

(More -- Over)

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Figure 4. Squib, Example No. 2

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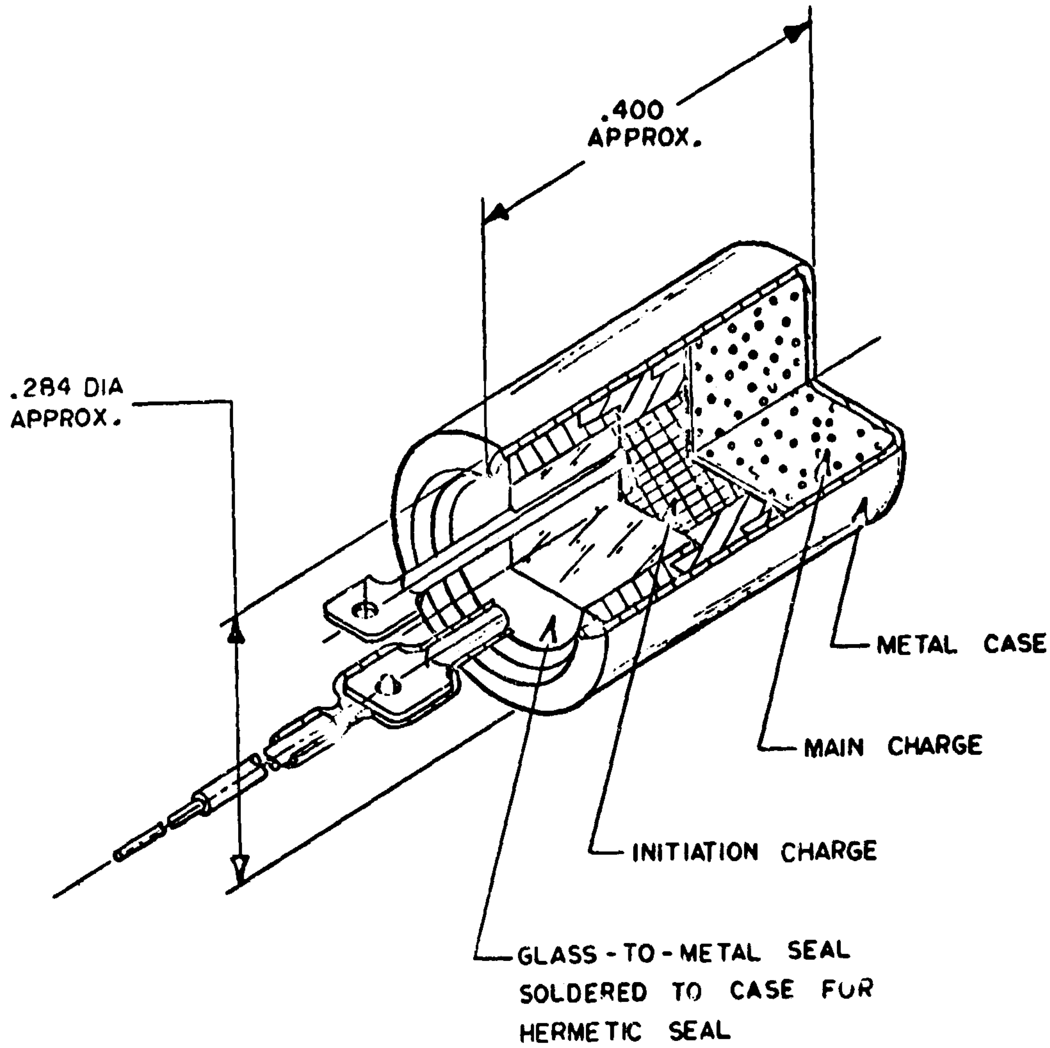


MODEL 209 ELECTRIC SQUIB

1 WATT - 1 AMPERE NO - FIRE

Figure 5. Squib, Example No. 3

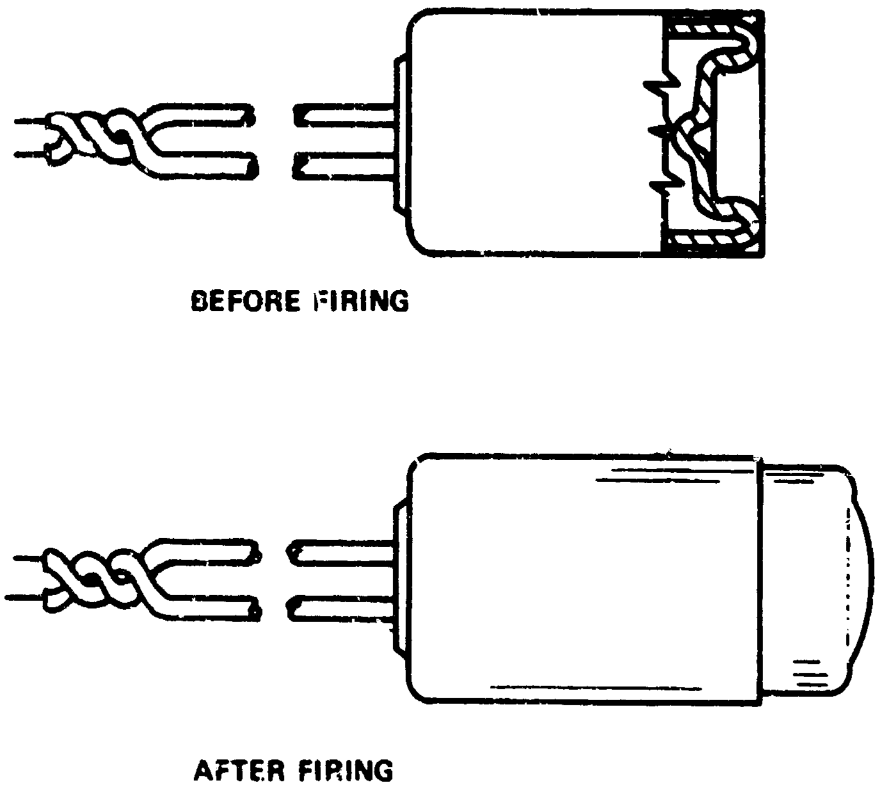


Figure 6. Dimple Motor

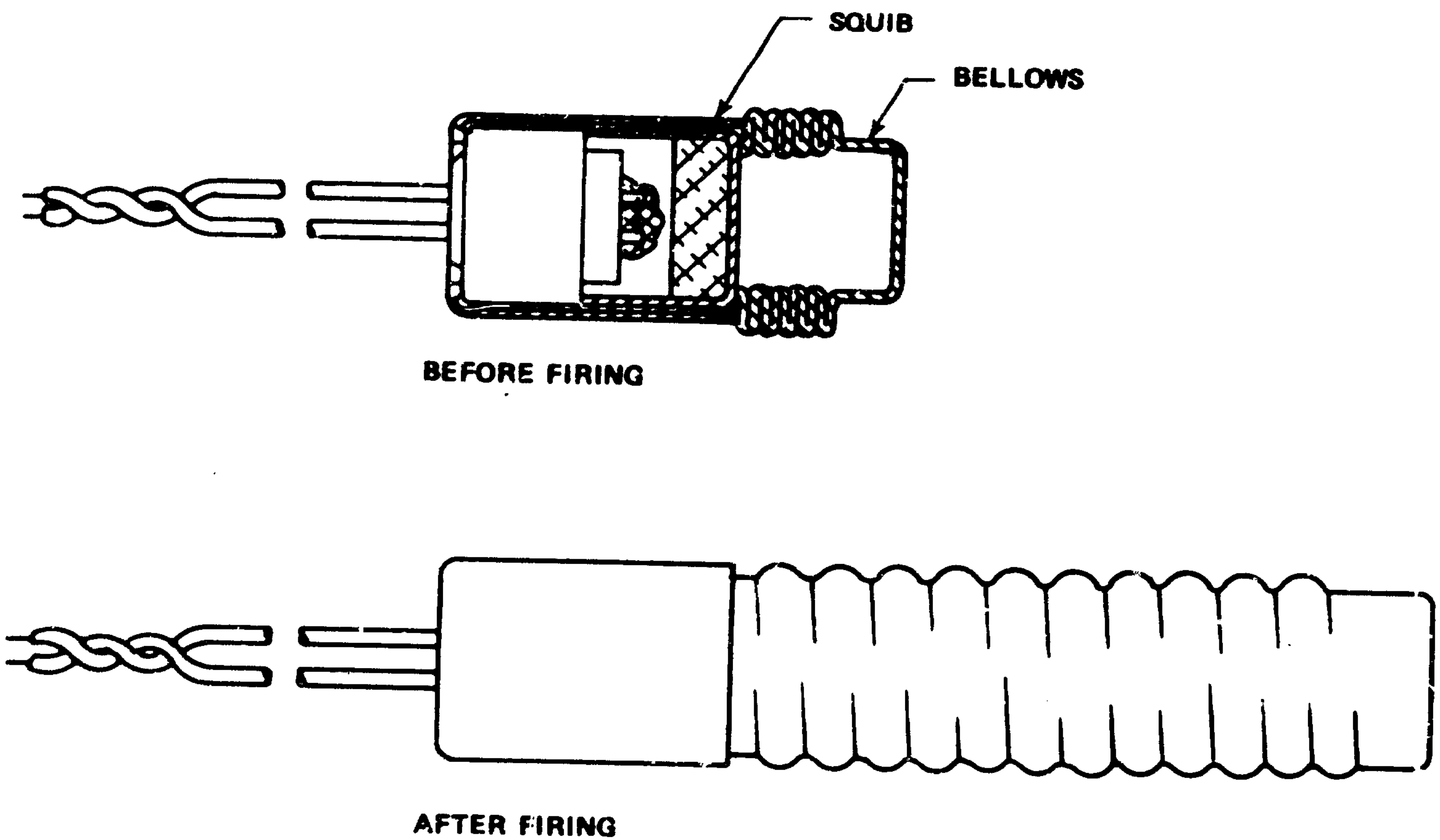


Figure 7. Bellcws Motor

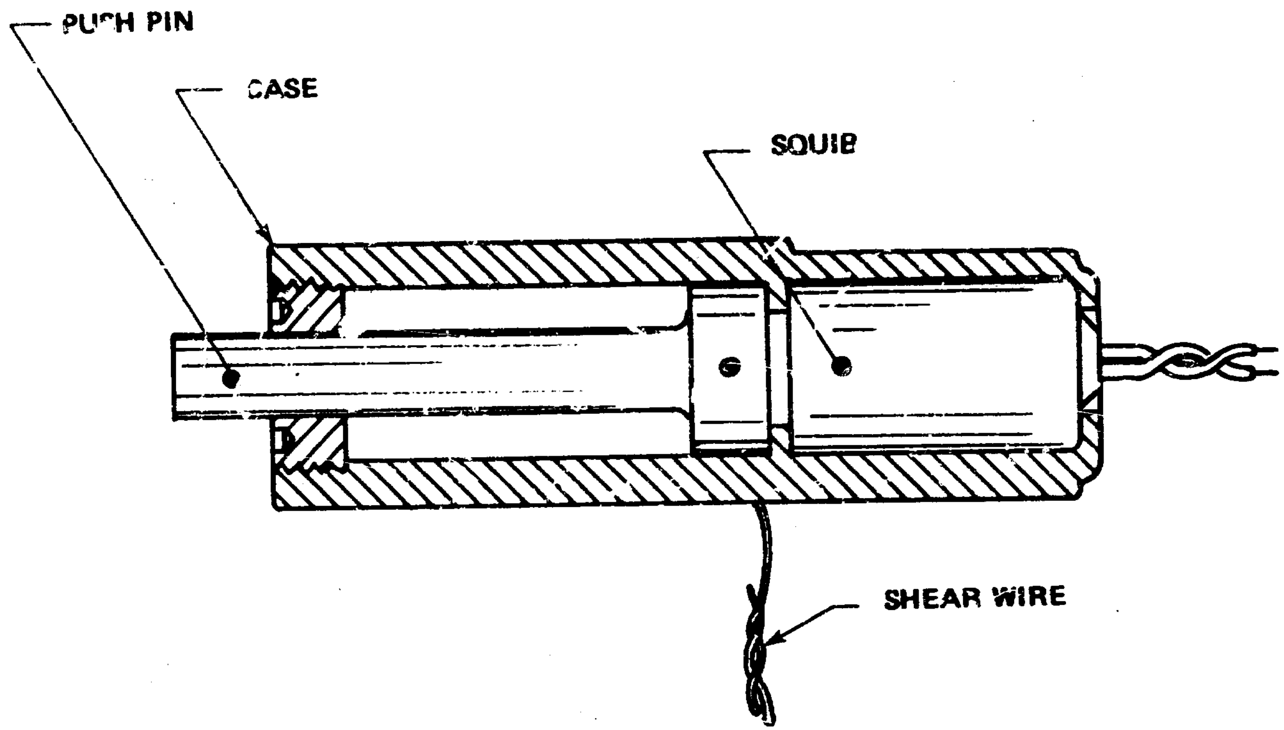


Figure 8. Puch-Pin Device (Before Firing)

SEPARATION

A separation device is one designed powerful enough to provide the energy needed to effect the separation desired. In this category, include explosive bolts, starp cutters, cable cutters, reefing line cutters, wire cutters, and nut separation. The above list does not include all separation devices available. In fact, these examples were designed for specific needs and applications.

A schematic example of an explosive bolt is shown in Figure 9. Figure 10 displays the reefing line cutter.

PRIMERS

A primer is very similar to a mild squib. Considerable variety exists in the number of electrical as well as mechanical types of primers. They are made with a relatively small and sensitive initial explosive train component which, on being activated, initiates functioning of the explosive train but will not reliably initiate high explosive charges.

Primers may easily be mistaken for squibs in that the packaging in each case may take the same form. Figure 11 depicts a mild end primer.

DETONATORS

A detonator, like a dynamite blasting cap, is designed, when properly used, to always detonate high explosives. A detonator is a complete explosive train in a single package, i.e., going from fire initiation-to-deflagration-to-detonation output or donor characteristics. See Figures 12, 13 and 14.

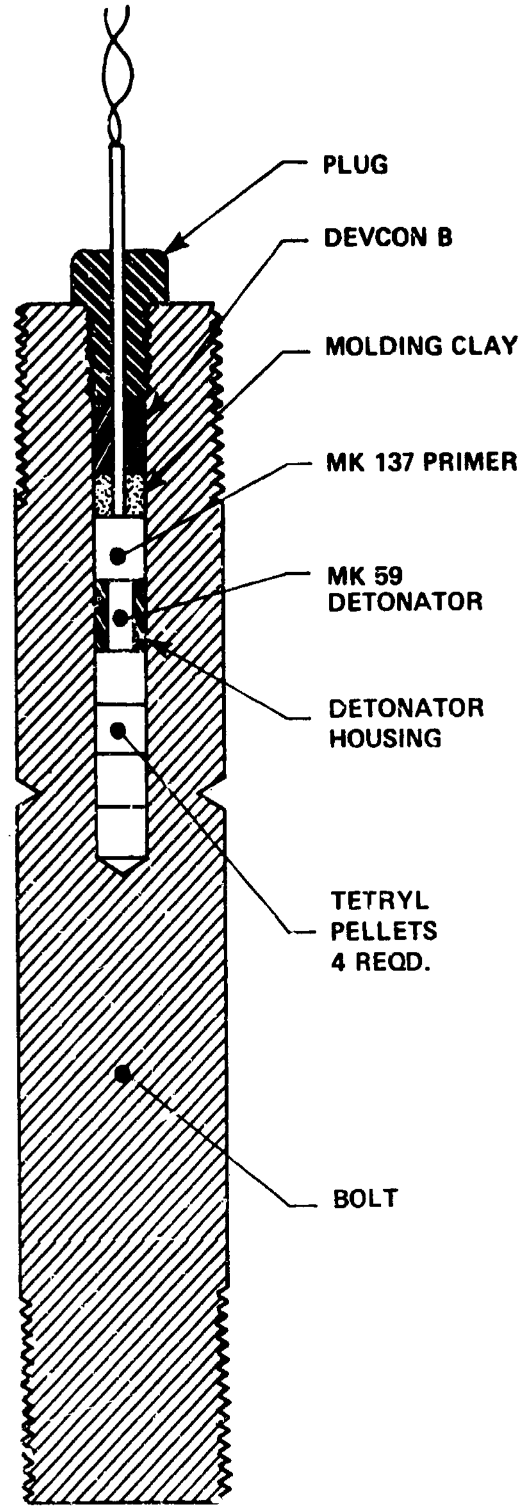


Figure 9. Explosive Bolt

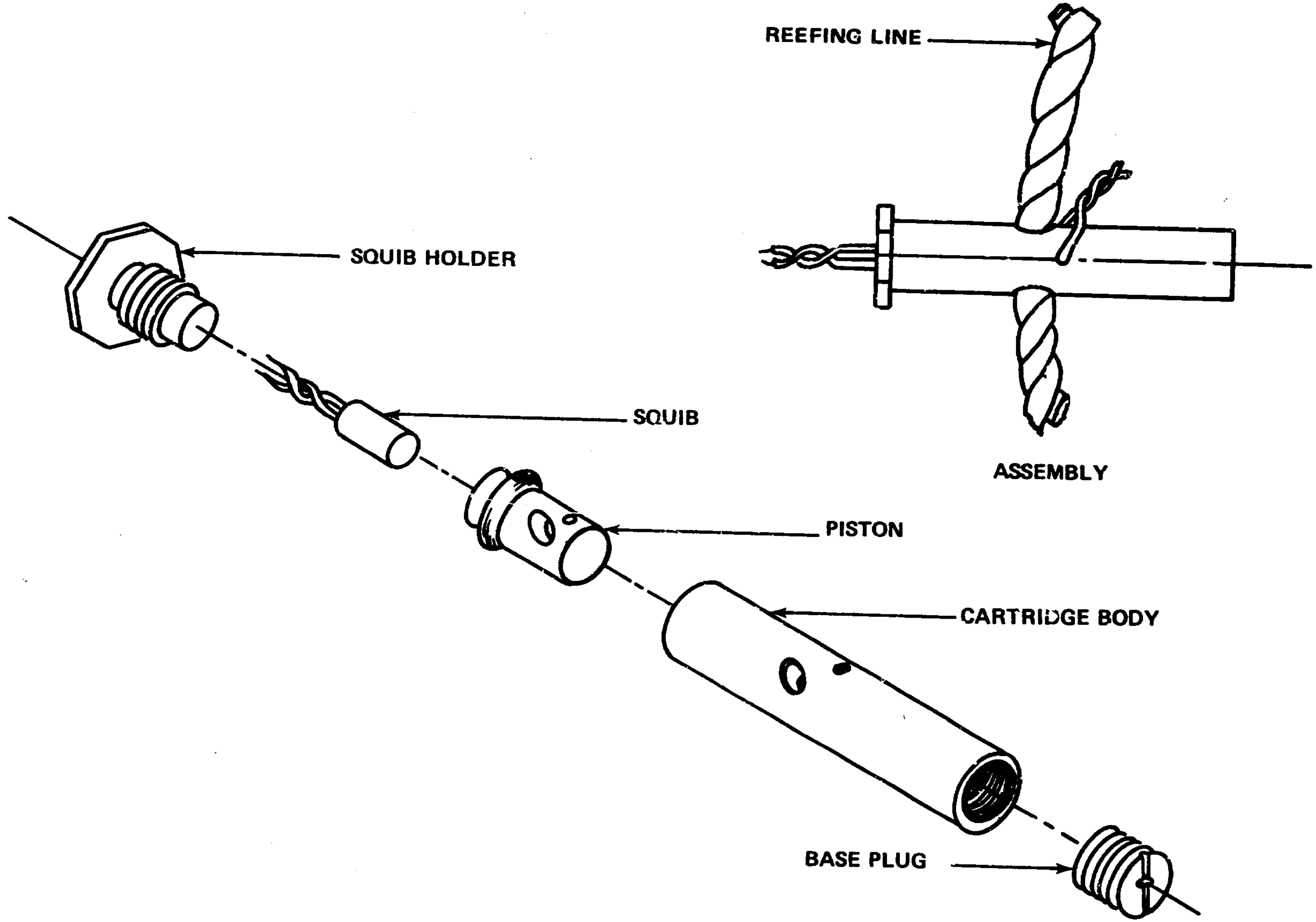
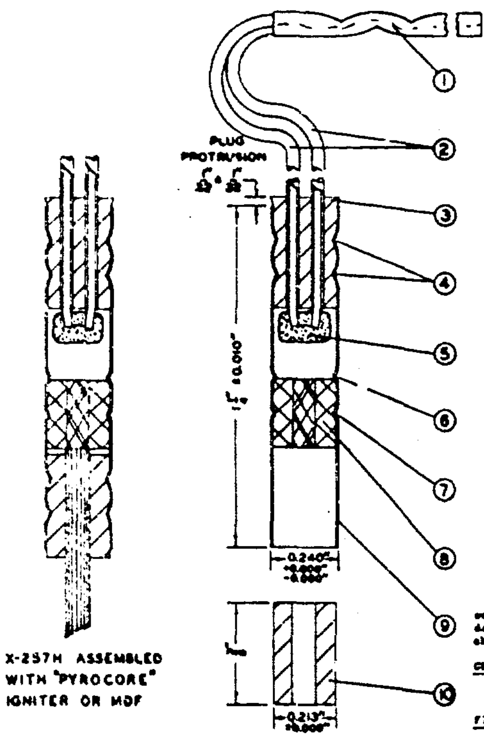


Figure 10. Reefing Line Cutter

DUPONT X-257H MILD END PRIMER

NOTICE
THIS DRAWING AND ACCOMPANYING DATA ARE INTENDED TO BE INFORMATIVE ONLY AND MUST NOT BE MADE THE BASIS FOR ANY SPECIFICATION WHATEVER.



X-257H ASSEMBLED WITH "PYROCORE" IGNITER OR MDF

X-257H AS SUPPLIED

(1) SHUNT	-	Cellophane-lined aluminum foil or plastic sleeve approximately 2-1/2 in. long around bared ends of leg wires.
(2) LEG WIRES	-	Plastic insulated, one blue and one yellow, 22 gage tinned copper; connecting ends bared for a distance of 1-7/8 in. to 2-1/4 in.
(3) RUBBER PLUG	-	Molded to leg wires and having bridge wire attached to bridge posts.
(4) CRIMPS	-	Completely around sleeve.
(5) IGNITION BEAD	-	Approximately 0.2 grain of du Pont No. 4 bead mixture secured to bridge wire with binder.
(6) CRIMP	-	Completely around sleeve.
(7) CARRIER CRIMPS	-	Four stake crimps spaced at 90° around shell.
(8) PRIMER CHARGE	-	Lead carrier loaded with approximately 1.3 grains of du Pont lead azide.
(9) SLEEVE	-	Aluminum alloy.
(10) GROMMET	-	Conductive rubber grommet supplied in a range of appropriate inside diameters for the various sizes of "Pyrocore" igniter and MDF.

RESISTANCE - The resistance of this primer is approximately 0.44 ± 0.25 ohm plus 0.032 ohm for each double foot of leg wire.

PERFORMANCE CHARACTERISTICS

The properties given below are based on background information or were determined in the Laboratory on initial lots of the primer. The data may vary with more exhaustive tests and are, therefore, subject to change.

GENERAL - This primer was developed to provide an electrical device having minimum brisance for initiation of MDF and "Pyrocore" igniter.

FIRING TIME - Time from application of current until assembly actuated stop circuit at end of 1-1/2 in. length of "Pyrocore" igniter installed in primer is shown in the graph at left.

HIGH TEMPERATURE PERFORMANCE - These primers when assembled with "Pyrocore" igniter functioned satisfactorily after storage at:
250°F. for 1 hour
210°F. for 24 hours
185°F. for over six weeks

IMPACT RESISTANCE - Primers consistently failed to detonate when struck by a ten pound weight dropped from a height of 34 in.

LOW PRESSURE PERFORMANCE - These primers when assembled with "Pyrocore" igniter functioned satisfactorily at 0.5 mm Hg. absolute.

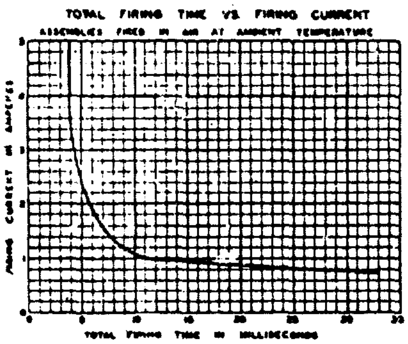
LOW TEMPERATURE PERFORMANCE - These primers when assembled with "Pyrocore" igniter functioned satisfactorily when conditioned and fired in dry ice. Firing times at this temperature averaged 5.8 ms. when fired with 3 amperes.

MINIMUM ENERGY REQUIRED FOR CONSISTENT FUNCTIONING - Minimum energy required by condenser discharge through leg wires for consistent ignition, 0.03 joule using 40 µfd. condenser.

MINIMUM FIRING CURRENT - Approximately 0.38 ampere average.

NO-FIRE CURRENT - Primers functioned satisfactorily (normal firing current and firing time) after being subjected to a current of 0.30 amp. for two minutes. Primers withstood 0.35 amp. current for two minutes without firing.

STATIC RESISTANCE - Maximum energy by condenser discharge from double leg wire-to-shell or "Pyrocore" (or MDF)-to-shell for ignition probability of zero 0.015 joule.

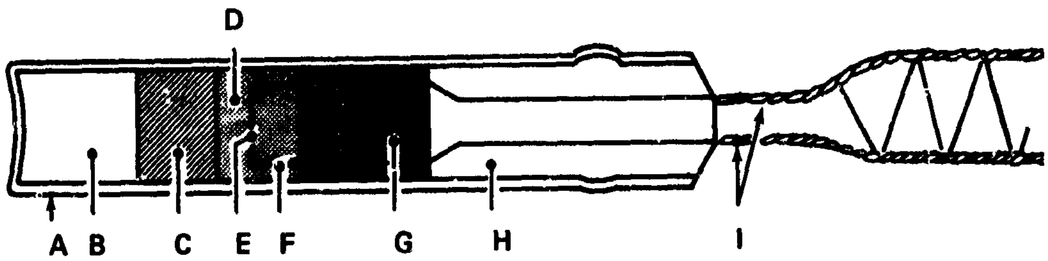


INQUIRIES CONCERNING THIS PRODUCT SHOULD SHOW PRODUCT DESIGNATION, PAGE DATE, AND BE ADDRESSED TO:

CHEMICAL SALES,
EXPLOSIVES DEPARTMENT
E. I. DUPONT DE NEMOURS & CO. INC.
WILMINGTON 98, DEL.

DATE 3-2-59

Figure 11. Mild End Primer



A METAL SHELL
B DETONATING CHARGE
C INTERMEDIATE CHARGE
D IGNITING CHARGE
E PLATINUM WIRE OR BRIDGE HEATED BY THE ELECTRIC CURRENT
F ENDS OF LEAD WIRES SET IN IGNITING CHARGE
G PLUG (ASPHALT)
H FILLING MATERIAL
I INSULATED LEAD WIRES

Figure 12. Cap, Blasting, Tetryl, Electric, Exteriors and Cross Section

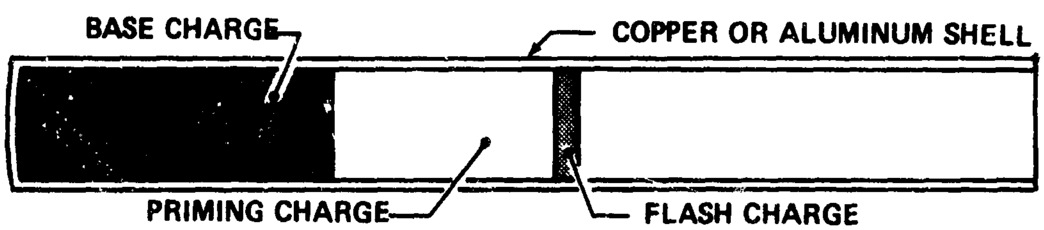


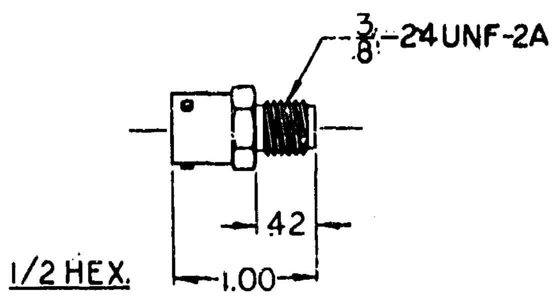
Figure 13. Cap, Blasting, Nonelectric

EXPLOSIVE ORDNANCE

NO. 3365 DETONATOR

Data contained herein is intended to be informative only and should not be used as the basis for any specification.

DESCRIPTION: The McCormick Selph 3365 Detonator was designed for Grand Central Rocket to initiate a mild end primer (duPont X-349 type) attached to detonating fuse through an air gap of 1/2" reliably (initiation through 2" air gap with confinement)



SPECIFICATIONS:

CONNECTOR: Mates with Bendix connector PT06E-8-2S.

CERAMIC: Withstands 10,000 psi applied in 10 milliseconds. Dielectric strength is a minimum of 10 megohms at 500 volts D.C..

CASE: 1/2 inch hexagonal steel (AISI B-1113 or equivalent).

MAIN CHARGE: 80 mg lead azide.

IGNITION BEAD: McCormick Selph No. 27.

BRIDGEWIRE: .00175 diameter Tophet "A". Bridgewire resistance 2.2 ± 0.3 ohms.

CLOSURE: .003 aluminum sealed with red epoxy.

FINISH: Cadmium plate per QQ-P-416, Type, Class 2.

RECOMMENDED INSTALLATION TORQUE: 40 inch lbs.

RECOMMENDED FIRING CURRENT: 5 amps.

CHECK OUT CURRENT: 10 milliamps or less.

(More -- Over)

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Figure 14. McCormick Selph 3365 Detonator

SECTION VII

IGNITERS AND IGNITION TRAINS

These terms are nearly always considered in combination in that the most recent igniters incorporate an ignition train. This fact is dictated by the specification packages for designs which will function over wide temperature ranges with minimum variation in time response, pressure rise, etc.

With respect to solid propellant ignition, three exceedingly practical designs have emerged from extensive research over the past 15 years.

PYROTECHNIC IGNITERS

Pyrotechnic igniters utilize powders or mixtures of powders, usually packaged in a plastic vessel, ignited by an electric squib. The powders are selected to produce hot particles which impinge upon the grain surface, heat and flame to raise the surface temperature of the grain to the ignition point and gas, to at least partially choke the nozzle, thereby adding to the overall ignitibility through pressure. Igniters of this type find use primarily in research and propellant development work where neither temperature extremes nor time limitations are a consideration.

They have, in the past, been used with motors such as the earlier Falcon series (Jelly Roll Pyrotechnic). Of course, the main disadvantage is their susceptibility to moisture, oxidation, reduction, caking, etc.

CONDUCTIVE FILM IGNITERS

This type of ignition is very seldom used but worthy of mention. As the name implies, it is a painted or fitted surface applied to all or

portions of a grain. It may incorporate pyrotechnic powders with a conductive metal which will aid in igniting all pyrotechnics at once as well as supplying heat to the grain from the induced current.

PELLET BASKET IGNITION

Pellet basket igniters have emerged as one of the two most successful and useful types. This is primarily because they offer wide latitudes in design criteria. An ignition grain is usually incorporated and may appear as follows. Energy from a squib housed in a safe-arm device is transmitted to a sealed column of pyrotechnics, housed in a multiperforated tube extending through the center of a basket or tube, housing ignition pellets. The pellets, in turn, provide the energy necessary to ignite the solid propellant grain.

This is a greatly simplified example but in operation is one of the most reliable systems in use. Considerable latitude is offered here by varying the charge of pyrotechnic powder to arrive at an optimum load which can better the functional requirements over a given temperature range. The size as well as the number of pellets required would be determined by the energy requirements of the grain for ignition. Here again, the pellets may be housed in a rigid, multiperforated tube or simply in a heavy steel-wire basket, either of which would be located close to the grain.

PYROGENS

Pyrogen igniters may be described simply as small rocket motors which ignite larger ones. Pyrogens usually require an ignition train to transmit enough energy to the main grain within the specified time envelope.

The pyrogen is perhaps the most widely used igniter, especially in larger motors, because of the extreme latitudes offered design-wise. The electro-initiating device and a pyrotechnic column may have severe limitations, but the actual ignition grain geometry provided the designer with almost unlimited freedom to produce the impetus required.

Examples of igniters are presented in Figures 15, 16 and 17.

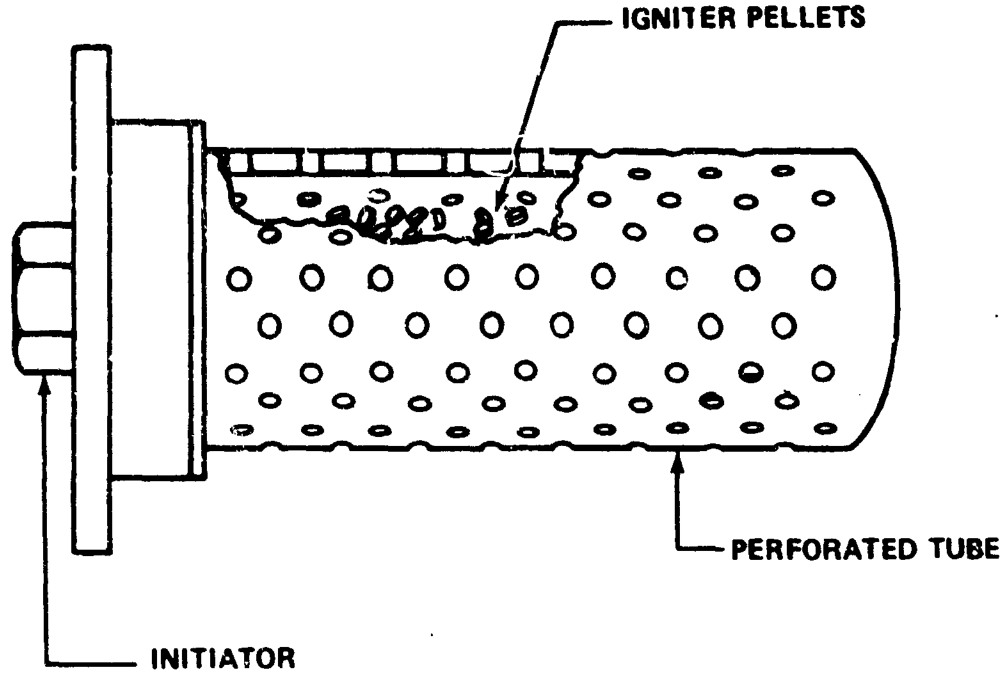

Figure 15. Typical Perforated Tube Igniter

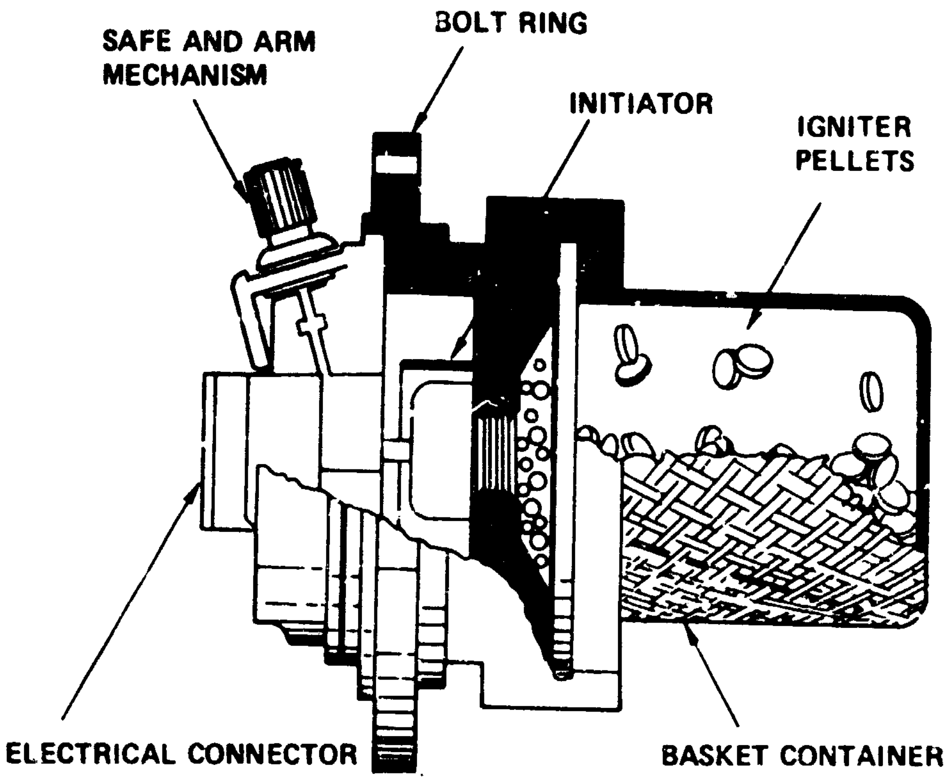

Figure 16. Typical Basket Igniter

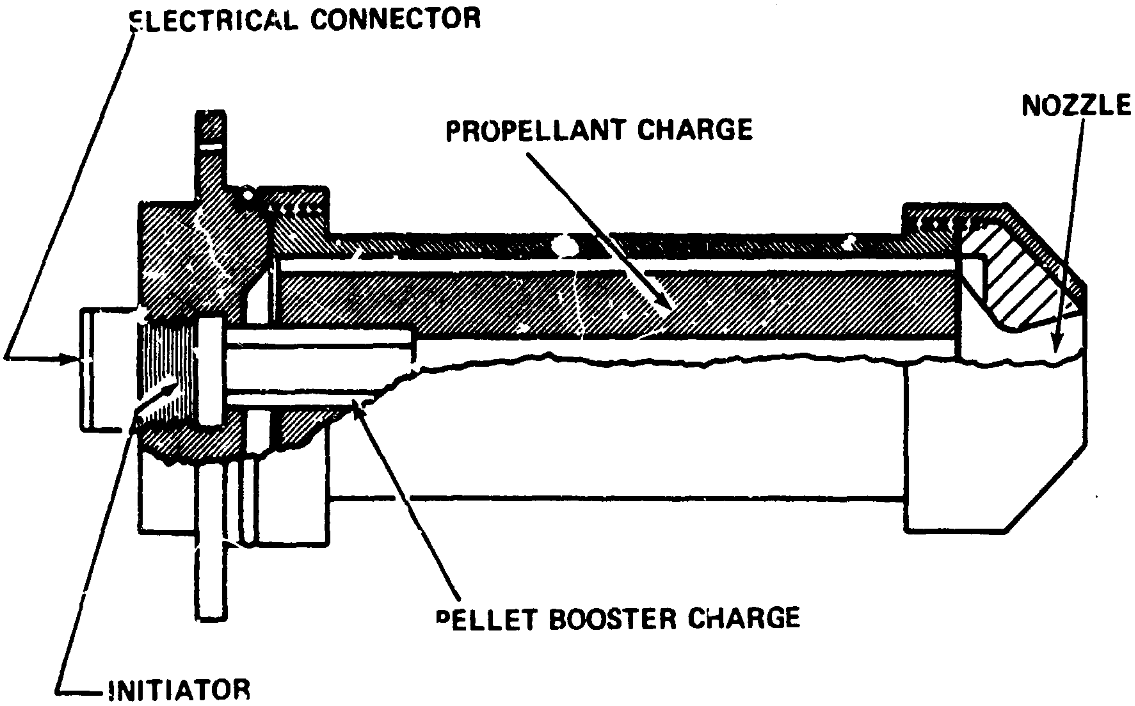

Figure 17. Typical Pyrogen Igniter

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